CHAPTER 2
TRENDS IN THE USE OF REMEDIAL TECHNOLOGIES AT NATIONAL PRIORITIES LIST SITES

The Nation faces a significant technological challenge to clean up its contaminated waste sites efficiently and effectively. The most comprehensive information on technology use at waste sites is available for the Superfund program. Although Superfund sites represent a small percentage of all contaminated sites, experience with technology applications at these sites is likely to influence technology selection in other market segments. The Superfund program has made great progress in selecting and applying new treatment technologies that are less costly and more effective. Nearly half of the remedial treatment decisions for source control (primarily soils) in recent years involve technologies that were not even available when the law was reauthorized in 1986. The development of new technologies has been driven by a preference for treatment in the reauthorized law and the resulting quest for more cost-effective processes. This chapter describes the historical trends in the selection of technologies at Superfund sites. For new or innovative technologies, it describes the status of their implementation, and the types and quantities of wastes being addressed.

2.1 The Superfund Program

Superfund is the federal program to clean up releases of hazardous substances at abandoned or uncontrolled hazardous waste sites. The program is administered by EPA under the authority of the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA). In addition to establishing enforcement authorities, CERCLA created a trust fund to be used for site identification and cleanup. The Superfund Amendments and Reauthorization Act of 1986 (SARA) made three important changes to the Superfund program that are of particular importance to technology vendors: (1) it stressed the importance of permanent remedies; (2) it supported the use of new, unproven treatment technologies; and (3) it expanded research and demonstrations to promote the development of innovative treatment technologies.

Superfund reauthorization is again being discussed in Congress, and some of the proposed provisions would affect the types of remedies selected. Some of the proposals are discussed in Chapter 3.

2.1.1 The National Contingency Plan

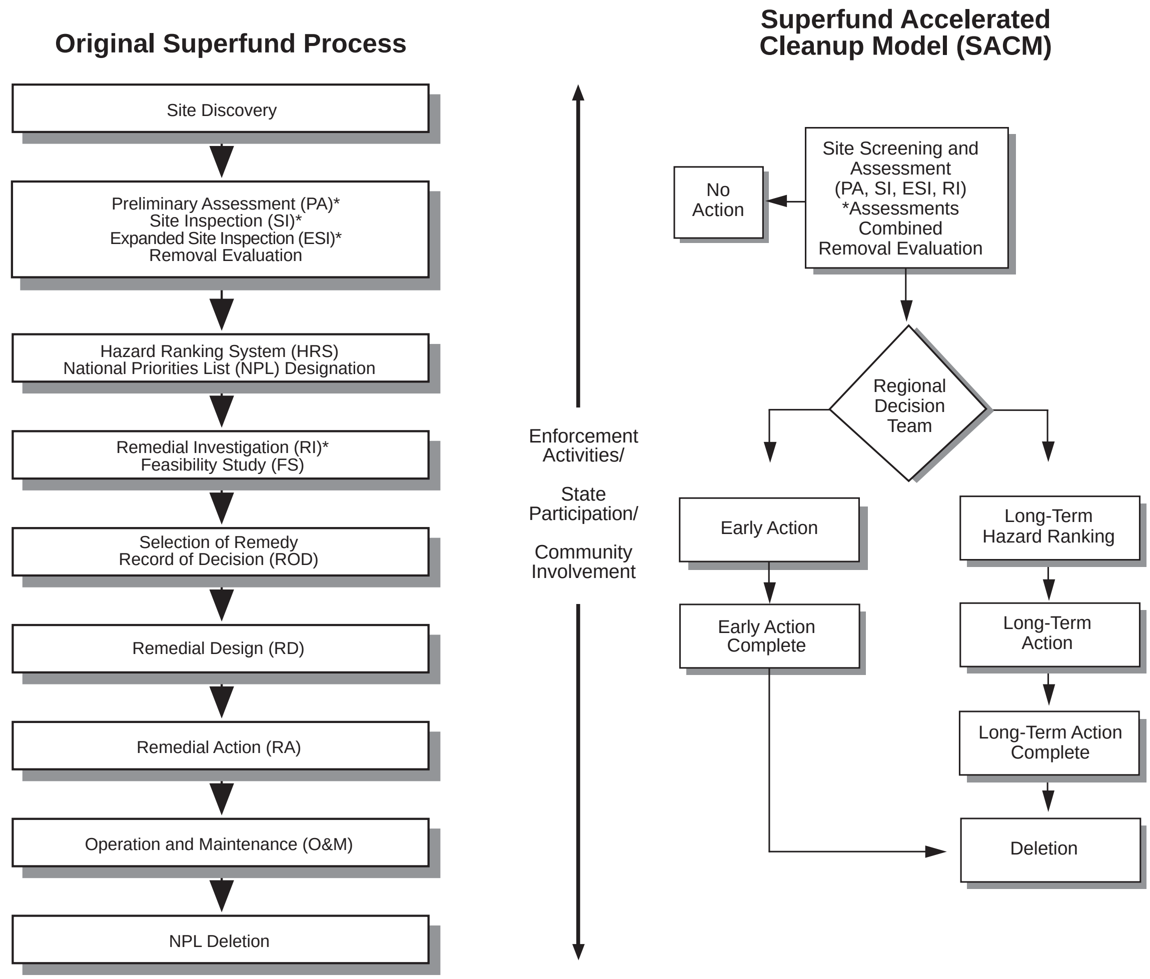
The procedures for implementing CERCLA are spelled out in the National Oil and Hazardous Substances Pollution Contingency Plan, commonly referred to as the National Contingency Plan (NCP). This plan outlines the steps that EPA and other federal agencies must follow in responding to releases of hazardous substances or oil into the environment. The goal described in the NCP is to select remedies that protect human health and the environment, maintain protection over time, and minimize untreated waste. The NCP specifies several treatment expectations to achieve this goal including:

- Use of treatment for principal threats wherever practical;
- Combination of treatment with containment, as necessary; and
- Consideration of innovative treatment technologies to the maximum extent practicable.

2.1.2 The Superfund Process

The site characterization and cleanup process established by the NCP is depicted in Exhibit 2-1. If more than one cleanup action is needed at a site, several steps in this process are repeated for each action. The process begins with the discovery of a potential hazardous waste site, and includes the following general steps:

Exhibit 2-1: Superfund Process Overview



* Indicates assessment phase of pipeline.

Source: U.S. EPA, Office of Emergency and Remedial Response.

1) A "preliminary assessment" (PA) is conducted to determine the existence of potential threats to human health or the environment that require a "removal action" or further study. If the PA indicates an emergency requiring immediate or short-term action to reduce the risk to the public, a removal action is conducted to stabilize or clean up the site.

2) If a hazard is identified or remains after a removal action is performed, a "site inspection" (SI) is conducted to determine whether a site warrants scoring under the Hazard Ranking System (HRS). EPA uses the HRS to score sites on the basis of potential human health and environmental effects from contamination and determine a site's eligibility for the National Priorities List (NPL). Sites with an HRS score of 28.5 or higher are proposed for the NPL, which is EPA's national list of sites with the worst contamination problems. Inclusion on the NPL means that the cleanup of the site can be accomplished using the Superfund Trust Fund.

3) When a site is added to the NPL, an in-depth planning and investigation phase begins, during which the nature and extent of contamination and site risks are determined, and treatment alternatives are evaluated. This phase is known as the “remedial investigation/feasibility study” (RI/FS). EPA requires the results of the RI/FS, including the rationale for selecting a remedy, to be presented to the public, and documented in a “Record of Decision” (ROD). Some sites require a series of RI/FSs and RODs to address different “operable units,” which are portions of a site reflecting pathways of exposure (*e.g.*, soil, water) that require separate cleanup actions.

   RODs provide useful information for technology vendors interested in gaining access to the hazardous waste cleanup market. First, RODs specify the technology type determined to be the appropriate remedy for a site. Second, technology vendors can use RODs to determine why EPA selected or rejected a specific remedy. EPA must consider nine criteria for remedy selection: overall protectiveness; compliance with other environmental laws and regulations; long-term effectiveness and permanence; short-term effectiveness; implementability; cost; and reduction of toxicity, mobility, or volume of wastes. State and community acceptance also are considered.

4) Following the ROD, detailed engineering specifications for the selected cleanup approach are developed. This phase is called “remedial design” (RD). The designs are used to solicit competitive bids to perform the “remedial action” (RA). In the RD phase, waste is actually treated, disposed, or contained. If necessary, “operation and maintenance” (O&M) begins at the conclusion of the RA. This phase can include such actions as groundwater monitoring and periodic site inspections to ensure continued effectiveness of the RAs. The final step in the process is to delete the site from the NPL. This step is initiated when all necessary cleanup responses under CERCLA are completed.

At any point in this process, an emergency requiring a removal action can occur at a site. In addition, community involvement activities take place throughout the process to ensure that all interested parties participate in the decision-making process. Enforcement actions that compel those responsible for the contamination to clean up the site also occur throughout the cleanup process to ensure optimal use of Trust Fund resources.

EPA is now implementing the Superfund Accelerated Cleanup Model (SACM). The purpose of SACM is to make hazardous waste cleanups more timely and efficient by integrating Superfund’s administrative components. The process is illustrated in Exhibit 2-1. Under SACM, EPA has adopted a continuous process for assessing site-specific conditions and the need for action. Risks will be reduced quickly through early action (removal or remedial). SACM operates within the existing statutory and regulatory structure. Superfund priorities will remain the same: deal with the worst problems first; aggressively pursue enforcement; and involve the public at every stage of the work.

As part of its responsibility for implementing the Superfund program, EPA is responsible for determining the best way to clean up each site. Other federal agencies such as the Department of Defense (DOD) and Department of Energy (DOE) are responsible for cleaning up NPL sites at their facilities in accordance with the requirements of the NCP and with EPA concurrence and oversight. Under the Superfund program, states also may take the lead to determine remedial alternatives and contract for the design and remediation of a site.

2.1.3 Program Status

Since its beginning in 1980, efforts under Superfund have included the identification and ranking of sites, detailed site investigation, mitigation of immediate threats, and selection and implementation of remedies to clean up the worst sites (those listed on the NPL). As of September 30, 1996, EPA had conducted preliminary assessments at 88 percent of the 12,657 potentially hazardous sites listed on the

Comprehensive Environmental Response, Compensation, and Liability Information System (CERCLIS), EPA's Superfund site tracking system.[a] EPA had listed 1,387 sites on the NPL, and proposed another 52 sites. Of these, 118 sites were deleted from the NPL, and six were referred to another authority leaving a total of 1,263 final NPL sites. As additional sites are studied and ranked, they may be added to the NPL.

In the past four years, the number of sites that have progressed from study and evaluation to actual cleanup has grown. By September 30, 1996, remedial construction activity was complete at 410 sites and construction was underway at 491 sites. Another 140 sites were in the RD phase and the remainder were in various stages of site investigation or remedy selection. In addition, EPA had conducted removal actions at 3,450 sites, over 80 percent of which are not currently NPL sites.[1]

The analyses of technology trends presented in this chapter are based on data from RODs signed between fiscal years (FYs) 1982 and 1995, which ended on September 30, 1995. During this period, EPA made cleanup decisions in 1,669 RODs for 1,070 NPL sites. The analyses described in this chapter are based primarily on these sites. Fiscal year 1995 is the latest year for which detailed ROD and site data are available.

2.2 History of Technology Use in Superfund

The types of remedial approaches selected have changed over time, partly in response to changes in regulatory authority and EPA policy and also as a result of the availability of specific technologies. This section reviews the broad trends in the use of hazardous waste remediation technologies at NPL sites.

2.2.1 Containment and Disposal Technologies

Since Superfund was established, the approach to cleaning up contaminated sites has evolved from emphasizing containment of waste to promoting waste treatment. Prior to 1987, the most common methods for remediating hazardous waste were to excavate the contaminated material and dispose of it in an off-site landfill, or to contain the waste on site by means of containment systems (*e.g.*, caps or slurry walls). Because SARA provided a preference for the use of permanent remedies for site cleanup, known as "alternative treatment technologies," the number of remedies that included treatment began to increase.

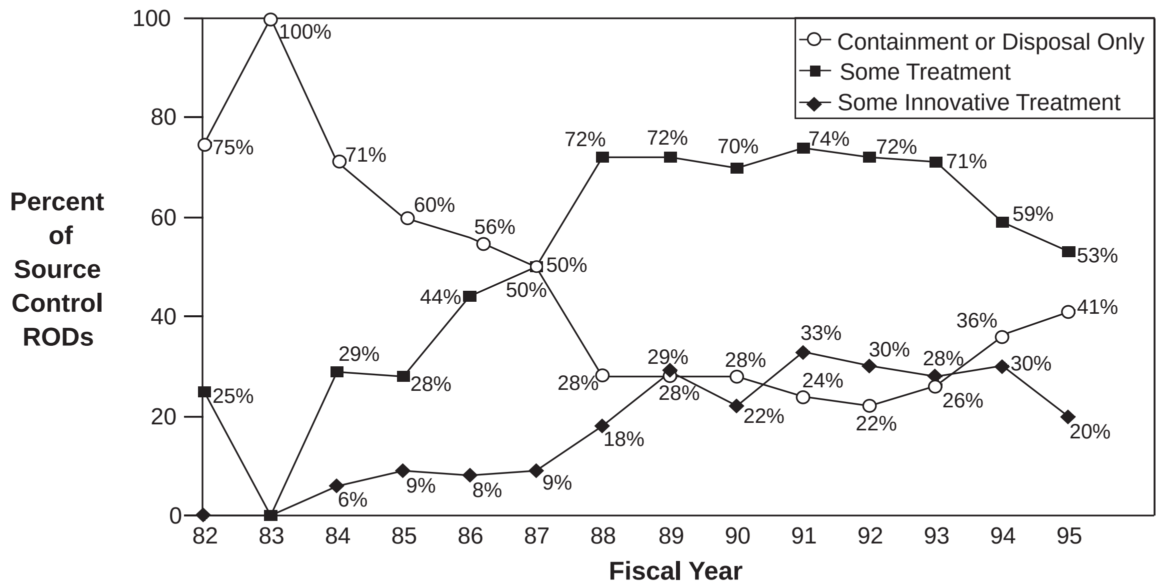
Of the 1,669 RODs signed between FY 1982 and FY 1995, 1,126 (67 percent) address the source of contamination: typically soil, sludge, sediment, or solid waste. Prior to 1987, more than half of these "source control" RODs specified the containment or disposal of the waste from the sites. From 1988 through 1993, almost three-quarters of all source control remedies involved some treatment to reduce the toxicity, mobility, or volume of waste (Exhibit 2-2). In the past two years, remedies have shifted toward containment used alone. This decline can be explained in part by an increase in the number of RODs for landfill sites and other difficult-to-treat wastes. Overall, more than 60 percent of all source control RODs signed between FY 1982 and FY 1995 included the treatment of some portion of the waste at the sites. In the future, the relative use of containment compared to treatment will greatly depend on the provisions of a forthcoming Superfund reauthorization.

2.2.2 Innovative and Established Technologies for Treatment

EPA's *Innovative Treatment Technologies: Annual Status Report (8th Edition)* contains information on each planned, ongoing, and completed treatment technology project selected for use in the Superfund program through FY 1995.[2] It also contains data on a limited number of non-Superfund federal facility sites *(i.e.*, DOD and DOE sites). Most of the discussion on the selection and use of innovative and established technologies presented in the remainder of this chapter is derived from this report.

[a] As of September 30, 1996, EPA removed and archived 28,008 sites from CERCLIS, in order to promote economic redevelopment at these sites by removing the stigma that may be associated with the presence of a site in CERCLIS. EPA, states, or tribes have completed evaluations at these sites, and no further work under the federal Superfund program is required.[1]

Exhibit 2-2: Treatment and Disposal Decisions for Source Control at NPL Sites



Notes: Data for innovative technologies are derived from Records of Decision (RODs) for fiscal years 1982-1995 and anticipated design and construction activities as of August 1996. A site may use more than one technology. Appendix Exhibit A-2 contains supporting data. Data for fiscal year 1995 are preliminary.

Source: U.S. EPA, Office of Solid Waste and Emergency Response, Technology Innovation Office, *Innovative Treatment Technologies: Annual Status Report (Eighth Edition)*, EPA 542-R-96-010, November 1996.

The frequency of use of established and innovative source control treatment technologies at NPL sites is shown in Exhibit 2-3. The technologies are grouped into 20 technology types, including 11 selected most frequently and nine "others." Fifty-seven percent of the 690 treatment technologies selected for source control are considered "established." Established remediation technologies are those that have sufficient published cost and performance data to support their regular use for site cleanup. The most frequently used established technologies are solidification / stabilization and incineration. "Innovative" remediation technologies are those for which sufficient published cost and performance data to support their regular use for site cleanup are not readily available.[b] In practice, the use of a number of remedial technologies that are considered innovative has increased at Superfund and other contaminated sites. In particular, a number of soil vapor extraction (SVE) and thermal desorption projects have been completed, and these technologies have become more accepted. However, because the results of most of the projects are not widely known, these two technologies are considered innovative for this report.

Solidification / stabilization (also called "fixation" and "immobilization") has been the most common technology to treat soil and other wastes. It accounts for 30 percent of all technology applications for source control at NPL sites between FY 1982 and FY 1995. However the use of this technology has declined since 1992 (Exhibit 2-4). Solidification / stabilization usually is selected to remediate metal containing waste and continues to be the favored technology to treat metals,

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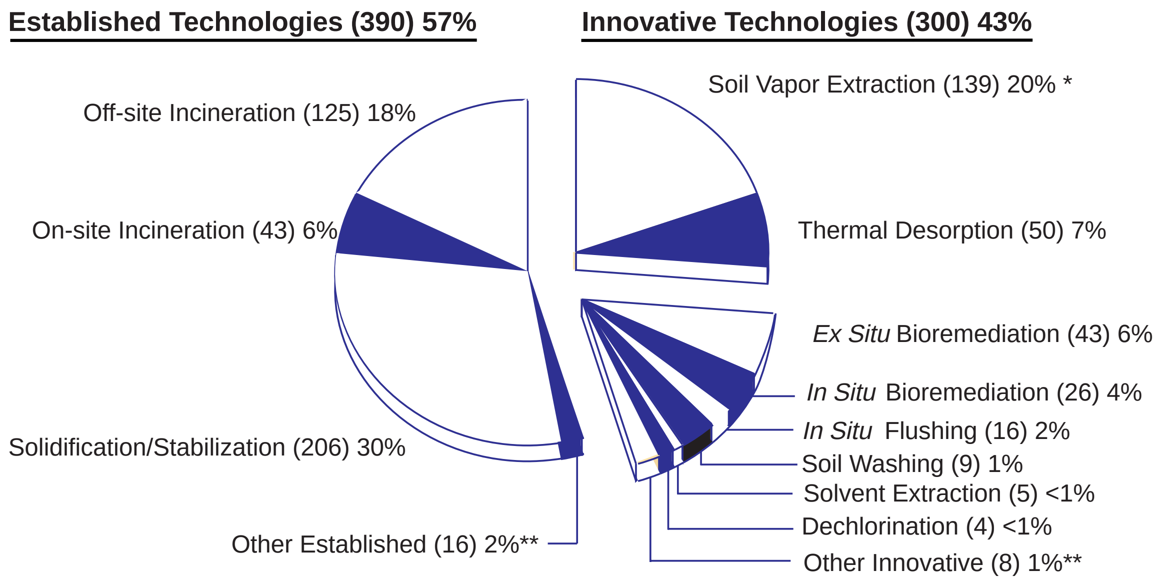
[b] Brief definitions of innovative technologies selected at Superfund sites, such as soil vapor extraction, soil washing, and dechlorination, are provided in Appendix G. Additional information on innovative technologies is provided in a technical screening guide published by several federal agencies.[3] Many other publications on both innovative and established remedial technologies are listed in a bibliography compiled by EPA,[4] and another compiled jointly by EPA and other federal agencies.[5]

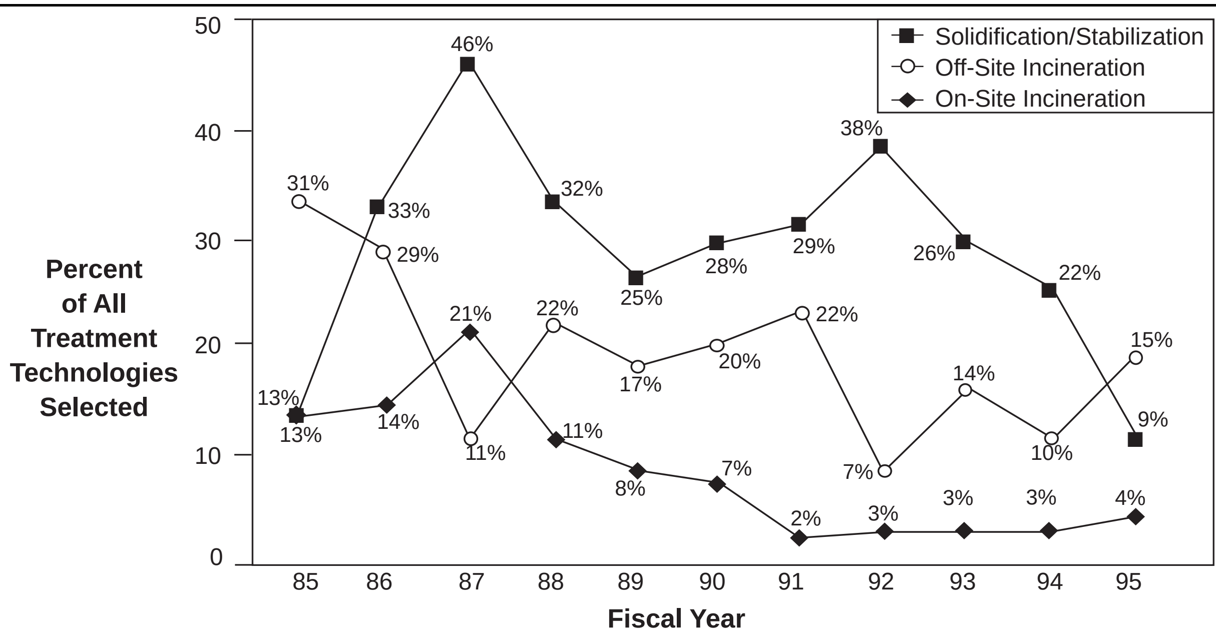
Exhibit 2-3: Source Control Technologies Selected for Superfund Sites Through Fiscal Year 1995



Notes: * Includes two dual-phase extraction projects also listed as *in situ* groundwater technologies.
** "Other" established technologies: soil aeration, open detonation, and chemical neutralization.
"Other" innovative technologies: physical separation, contained recovery of oily wastes (CROW™), cyanide oxidation, vitrification, hot air injection, and plasma high-temperature metals recovery.

Source: U.S. EPA, Office of Solid Waste and Emergency Response, Technology Innovation Office, *Innovative Treatment Technologies: Annual Status Report (Eighth Edition)*, EPA 542-R-96-010, November 1996.

Exhibit 2-4: Trends for the Most Frequently Selected Established Technologies for Source Control at NPL Sites



Note: Few treatment technologies were selected in the earlier years of the Superfund Program: one in 1982, none in 1983, four in 1984, and 12 in 1985.

Source: Adapted from U.S. EPA, Office of Solid Waste and Emergency Response, Technology Innovation Office, *Innovative Treatment Technologies: Annual Status Report (Eighth Edition),* EPA 542-R-96-010, November 1996.

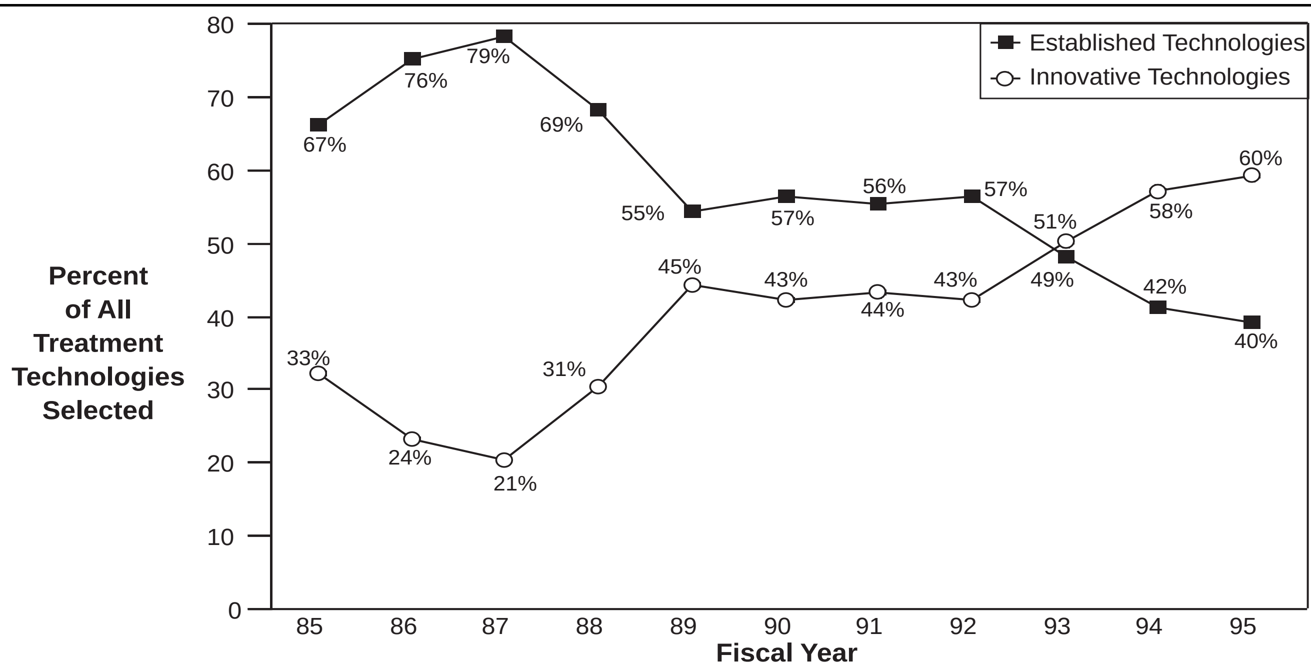
although some compounds are not easily solidified. In some cases, it is selected to treat organic contaminants, primarily semivolatile organic compounds (SVOCs). Although solidification/stabilization has several advantages, including low cost, questions remain concerning its effectiveness over time. Consequently, it may require long-term monitoring.

Incineration has been the second most frequently selected technology for treating soil, sludge, and sediment in Superfund and was the first technology available for treating organic contaminants in these matrices. The major advantage of incineration is its ability to achieve stringent cleanup standards for highly concentrated mixtures. On-site and off-site incineration together accounted for 24 percent of all treatments selected for source control through FY 1995. However, based on recent project data, on-site incineration is seldom being used (Exhibit 2-4). Off-site incineration is more applicable to smaller quantities (typically less than about 5,000 cubic yards) of highly contaminated material and for residuals of pre- or post-treatment technologies that separate and concentrate contaminants.

While solidification/stabilization and incineration (both established technologies) have accounted for a decreasing share of all technologies selected for source control for Superfund sites, the share accounted for by innovative treatments has grown (Exhibit 2-5). In FY 1993, for the first time, over half of the treatment technologies selected for source control were innovative; and about 20 percent of all sites with RODs are using at least one innovative technology. The most widely selected innovative technology, SVE, was selected for 20 percent of source control technologies selected through FY 1995 (Exhibit 2-3). The other most common innovative technologies are bioremediation, thermal desorption, *in situ* flushing, and soil washing. Trends in selection of the three most commonly used innovative technologies are shown in Exhibit 2-6.

Seventy-six percent of Superfund sites with RODs require some sort of groundwater remediation. In most cases groundwater is being addressed by pump-and-treat technology, in which groundwater is pumped to the surface to be treated by physical/chemical methods (Exhibit 2-7). For this report, all above-ground treatment of ground-

Exhibit 2-5: Relative Use of Established and Innovative Technologies for Source Control at NPL Sites



Note: A site may use more than one technology.

Source: Adapted from U.S. EPA, Office of Solid Waste and Emergency Response, Technology Innovation Office, *Innovative Treatment Technologies: Annual Status Report (Eighth Edition),* EPA 542-R-96-010, November 1996.

water is considered established, although some innovative approaches are being developed for aqueous treatment. All *in situ* treatment technologies for groundwater are considered innovative. *In situ* groundwater remedies have been selected for fewer than six percent of groundwater sites. Of 603 sites for which groundwater remedies have been selected, pump-and-treat technology alone is being implemented at 93 percent and is combined with *in situ* treatment at 5 percent of the sites. *In situ* treatment alone has been selected for only nine sites.

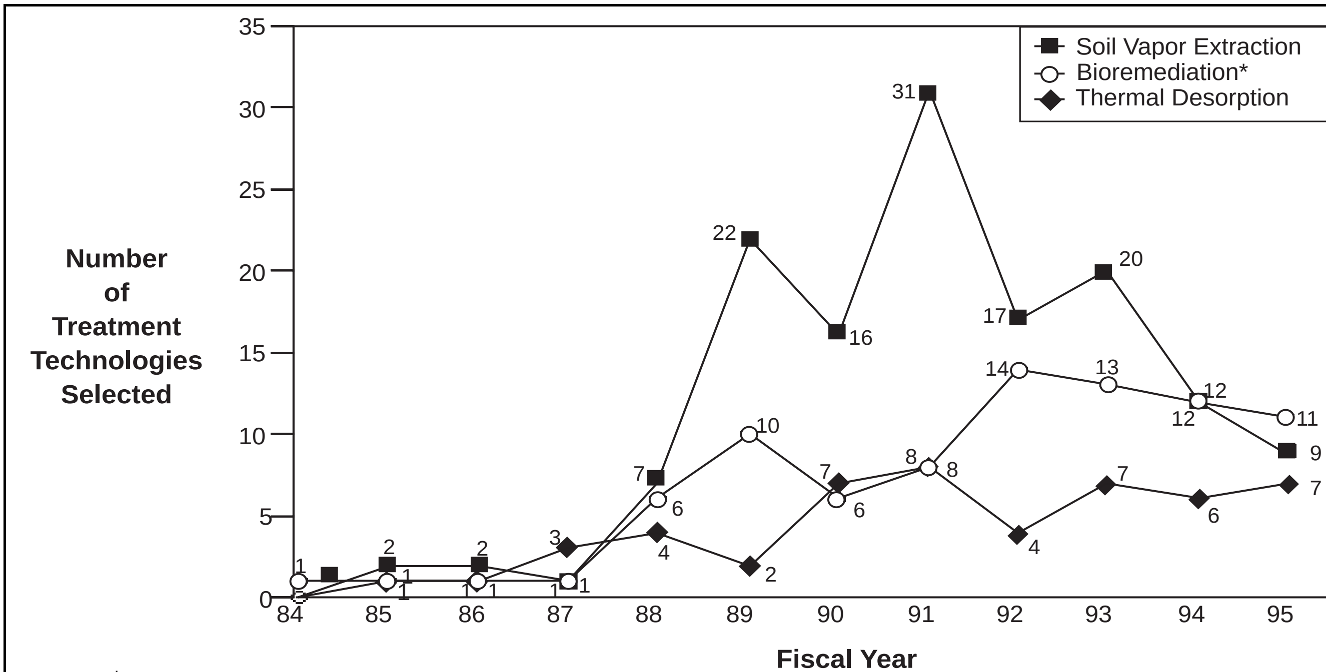
2.3 Innovative Remedies for Source Control

EPA closely tracks the status of innovative technology projects at NPL sites. Exhibit 2-8 provides the implementation status of innovative treatment technologies selected for Superfund sites. Fifty-six projects using innovative technologies have been completed as of August 1996. Consequently, operating experience is limited but growing for innovative technologies chosen at Superfund sites.

The innovative treatment projects now in design will be implemented within the next several years. As of August 1996, innovative treatment technologies for source control and groundwater were designed, or being installed for 174 projects, and operational for 99 projects. Another 114 projects were at the predesign or design stages. As these projects are implemented and completed, EPA will make available more complete information on full-scale cost and performance for many sites.

Exhibit 2-9 presents a cumulative account of how often the seven most commonly used types of innovative remedies for source control have been selected to treat each of the three major contaminant groups: VOCs, SVOCs, and metals. Although not reflected here, the presence of other contaminant groups or specific site conditions also may affect the technology selection. Since technologies may target more than one constituent, these numbers are not additive. The following subsections address each of the three contaminant groups.

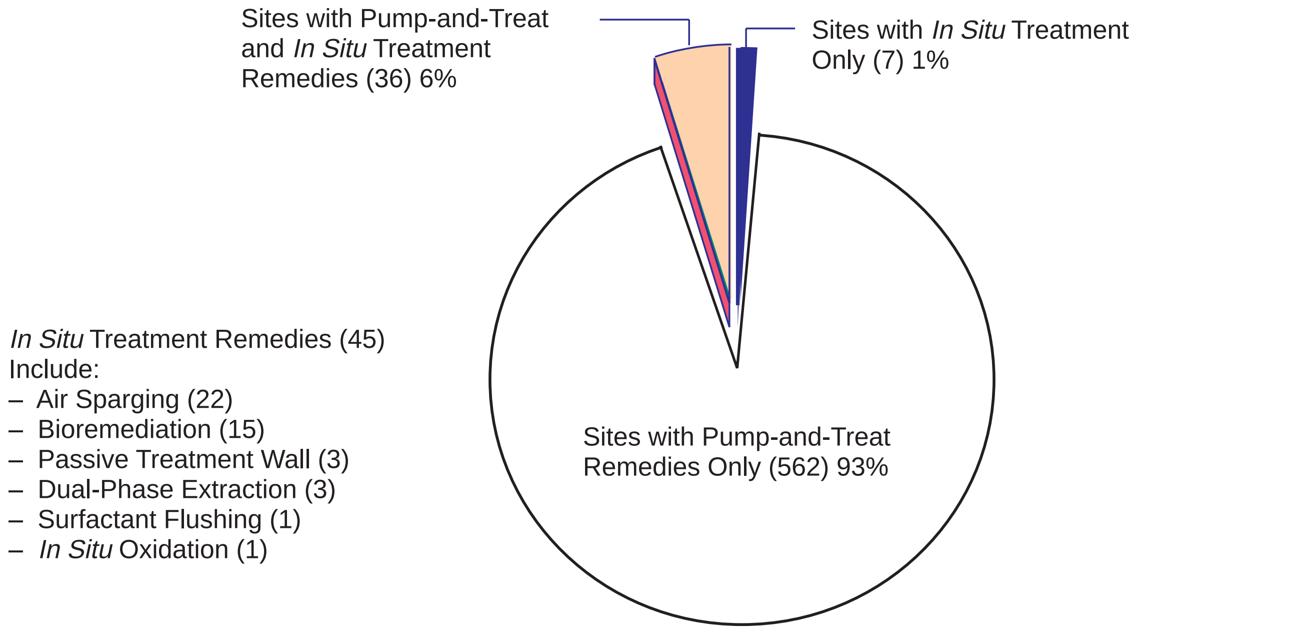
Exhibit 2-6: Trends for the Three Most Frequently Selected Treatment Technologies at NPL Sites



Notes: * Also includes *in situ* groundwater treatment.

Source: U.S. EPA, Office of Solid Waste and Emergency Response, Technology Innovation Office, *Innovative Treatment Technologies: Annual Status Report (Eighth Edition),* EPA 542-R-96-010, November 1996.

Exhibit 2-7: Groundwater Treatment Remedies at NPL Sites Through Fiscal Year 1995



Notes: Does not include groundwater sites with nontreatment remedies (*i.e.*, monitoring, institutional controls, alternate water supply, well-head treatment, closing wells, containment, or natural attenuation).

Source: U.S. EPA, Office of Solid Waste and Emergency Response, Technology Innovation Office.

2.3.1 Treatment of Volatile Organic Compounds

Of the three major contaminant groups, NPL sites with VOCs are the most frequently treated with innovative technologies (Exhibit 2-9). SVE has become the preferred technology for both chlorinated and nonchlorinated VOCs in soil. Despite its frequent selection, SVE is still considered innovative in this report because its effectiveness has not been confirmed for many types of sites, and because the results of many projects are not yet widely known. The selection of SVE for Superfund sites has decreased recently (Exhibit 2-6).

The overall popularity of this technology is due to its low cost and the frequent occurrence of VOCs at Superfund sites. Although performance varies from one application to another, SVE usually is the most cost-effective means of reducing VOC concentrations. SVE has been selected in some cases to pretreat soils prior to excavation or subsequent treatment. At some sites, SVE may be modified to enhance *in situ* bioremediation (called "bioventing"). Bioventing optimizes SVE performance by maximizing the biodegradation of certain organics by controlling the air flow. Bioventing also may lead to increased use of SVE when VOCs and SVOCs are present. Other means of expanding the range of application of SVE include integrating with groundwater treatment technologies such as dual-phase extraction and air sparging, improved well placement, and improved recovery through hydraulic or pneumatic fracturing and thermal processes. Further developments that may expand the application of SVE include radio frequency heating, horizontal well techniques, and other methods to increase soil permeability. Overall, 18 SVE projects have been completed at NPL sites and 52 are operational.

Thermal desorption and bioremediation also are commonly used to treat VOCs. Bioremediation is usually applied to non-halogenated VOCs, such as benzene (Exhibit 2-9).

2.3.2 Treatment of Semivolatile Organic Compounds (SVOCs)

Bioremediation and thermal desorption are the most frequently selected innovative technologies for NPL sites with SVOCs. In addition, soil vapor extraction has been selected for some of the more

Exhibit 2-8: Status of Innovative Technology Projects at NPL Sites as of August 1995

Technology	Predesign/ In Design	Design Complete/ Being Installed	Operational	Completed	Total
Source Control Technologies					
Soil Vapor Extraction	36	33	52	18	139
Thermal Desorption	14	8	4	24	50
Ex Situ Bioremediation	16	8	14	5	43
In Situ Bioremediation	9	5	10	2	26
In Situ Flushing	7	2	6	1	16
Soil Washing	6	2	0	1	9
Solvent Extraction	2	2	0	1	5
Dechlorination	1	1	0	2	4
Vitrification	2	0	0	1	3
Cyanide Oxidation	1	0	0	0	1
Hot Air Injection	1	0	0	0	1
Contained Recovery of Oily Wastes (CROW™)	0	0	0	1	1
Physical Separation	0	0	0	1	1
Plasma High Temperature Metals Recovery	1	0	0	0	1
Total	**96 (32%)**	**61 (20%)**	**86 (29%)**	**57 (19%)**	**300**
Groundwater Technologies					
Air Sparging	6	8	8	0	22
In Situ Bioremediation	7	5	3	0	15
Passive Treatment Wall	3	0	0	0	3
Dual-Phase Extraction	1	2	0	0	3
In Situ Well Aeration	1	0	0	0	1
In Situ Oxidation	0	1	0	0	1
Total	**18 (40%)**	**16 (36%)**	**11 (24%)**	**0**	**45**

Notes: Data are derived from Records of Decision for fiscal years 1982-1995 and anticipated design and construction activities as of August 1996.

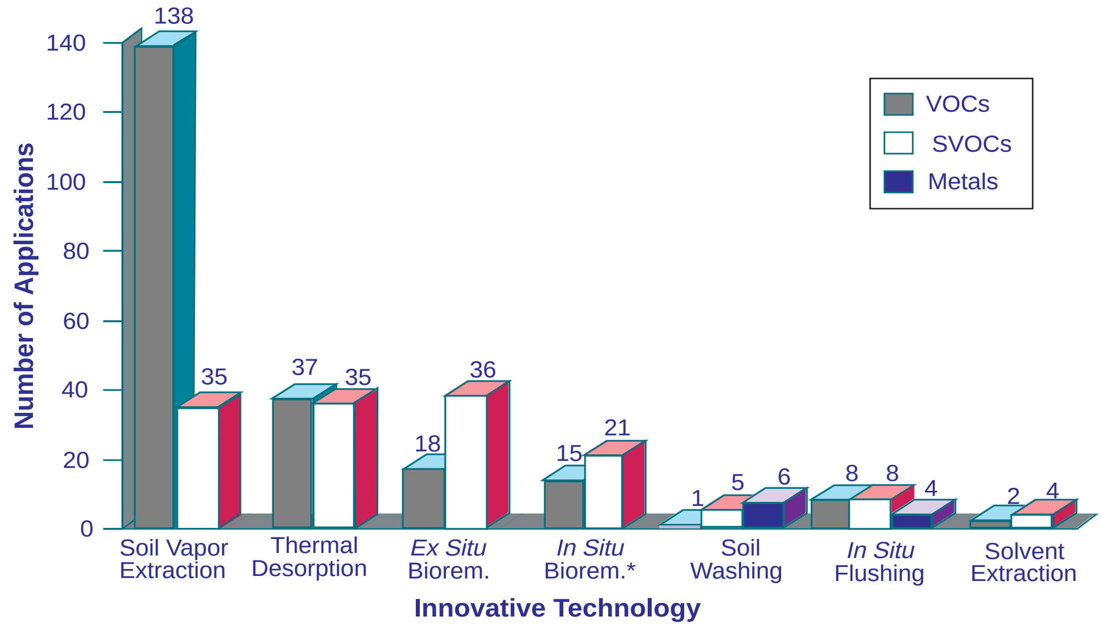
Source: U.S. EPA, Office of Solid Waste and Emergency Response, Technology Innovation Office, *Innovative Treatment Technologies: Annual Status Report (Eighth Edition)*, EPA-542-R-96-010, November 1996.

volatile SVOCs (*e.g.*, phenols and naphthalenes).[6] Other technologies used to treat SVOCs are dechlorination, vitrification, and contained recovery of oily waste (CROW™).[6]

Bioremediation methods selected include land treatment, *in situ* treatment, and slurry-phase treatment. Bioremediation has been selected for 47 projects to treat polyaromatic hydrocarbons (PAHs) and 10 projects to treat other SVOCs.[6] Overall, seven bioremediation projects for source control have been completed and 24 are operational. From 1992 to 1995, bioremediation for source control was chosen 10 times per year, on average.[2]

Since bioremediation destroys organic contaminants, it has a major advantage over other innovative technologies that rely on separation techniques. Nevertheless, bioremediation has not been selected more often at Superfund sites, probably because, in its current state of development, it addresses a limited number of biodegradable compounds; and many site conditions (such as the presence of metals and clayey soil) inhibit performance. Bioremediation also may have difficulty meeting stringent cleanup levels or may require long periods of time to achieve the required reductions. Current research efforts are focused on biodegradation of chlorinated aliphatic hydrocarbons, such as

Exhibit 2-9: Applications of Innovative Treatment Technologies for Source Control at NPL Sites



Notes: Includes technologies selected in Records of Decision for fiscal years 1982-1995.
* Does not include *in situ* groundwater bioremediation.

Source: U.S. EPA, Office of Solid Waste and Emergency Response, Technology Innovation Office, *Innovative Treatment Technologies: Annual Status Report (Eighth Edition),* EPA 542-R-96-010, November 1996.

trichloroethylene (TCE) and vinyl chloride, which occur at many sites.

Thermal desorption treats a broad spectrum of SVOCs, most frequently PAHs and PCBs. In all, 24 thermal desorption projects have been completed and four are operational (Exhibit 2-8). Thermal desorption may be particularly well-suited for pretreating organics prior to metals treatment. Soil washing has been selected five times to treat SVOCs, such as PAHs, phenols and pesticides, and one soil washing project has been completed. Dechlorination, a form of chemical treatment, also has been selected to treat PCBs for four projects, two of which have been completed.[5],[6]

2.3.3 Treatment of Metals

The most frequently selected technology for metal waste is solidification / stabilization, which has been selected for 206 projects (Exhibit 2-3). In the past two years, its selection has decreased substantially. Of the innovative technologies, soil washing is being used to remediate metals at six sites, three of which also contain organics. *In situ* flushing has been selected for three projects to treat metallic wastes, two of which also contain organics, and at one site to treat arsenic. The application of *in situ* flushing is largely dependent on site hydrogeology, which must carefully be considered to reduce the possible spread of contamination. In this process, contaminants may leach into underlying groundwater, from which they are typically recovered by pump-and-treat methods. Some new methods under development to remediate metals include phytoremediation and electrokinetics.

No treatment technologies have yet been selected at NPL sites with low-level radioactive metals combined with other hazardous constituents (known as “mixed wastes”). In the past, the selected remedy has been excavation and on-site storage, or disposal in an on- or off-site landfill permitted to accept such waste. DOE is testing and implementing several technologies, such as vitrification, to address radioactive contaminants.

Often, “treatment trains” are use to address media and wastes containing both metals and organics. A “treatment train” is the combined use of several treatment technologies in a series in order to: reduce the volume of material requiring subsequent treatment; prevent emission of volatile contaminants during excavation and mixing; or address multiple contaminants within the same medium. Treatment trains that use innovative technologies have been selected at 32 Superfund sites (Exhibit 2-10), 18 of which use established technologies as part of the treatment train.

2.3.4 Waste Matrices and Quantities

Of the 345 innovative technology projects selected at Superfund sites, 300 address source control and 45 are for the treatment of groundwater *in situ*. Of the innovative technology applications for source control, soil is addressed at 99 percent of the sites, sludge at six percent, sediments at five percent, and solids at less than one percent.[6] The total exceeds 100 percent because each technology may be used to treat more than one waste matrix at a site. As shown in Exhibit 2-11, the quantities of soil treated by the various innovative techniques vary widely from one site to another. In general, *in situ* technologies such as *in situ* flushing, SVE, and *in situ* bioremediation have been chosen to treat larger volumes of soil. These three technologies account for over 90 percent of the soil and other material to be treated by innovative technologies for those sites where data are available. Technologies that treat excavated wastes or require waste postprocessing (*e.g.*, soil washing, thermal desorption, and solvent extraction) generally are selected to treat smaller amounts of soil.

2.4 Innovative Remedies for Groundwater

Of the 45 applications of innovative technologies to groundwater at 44 sites, 36 address VOCs, 17 address SVOCs, and two address metals. The most frequently selected innovative groundwater technologies are air sparging, selected 22 times, and bioremediation, selected 15 times.

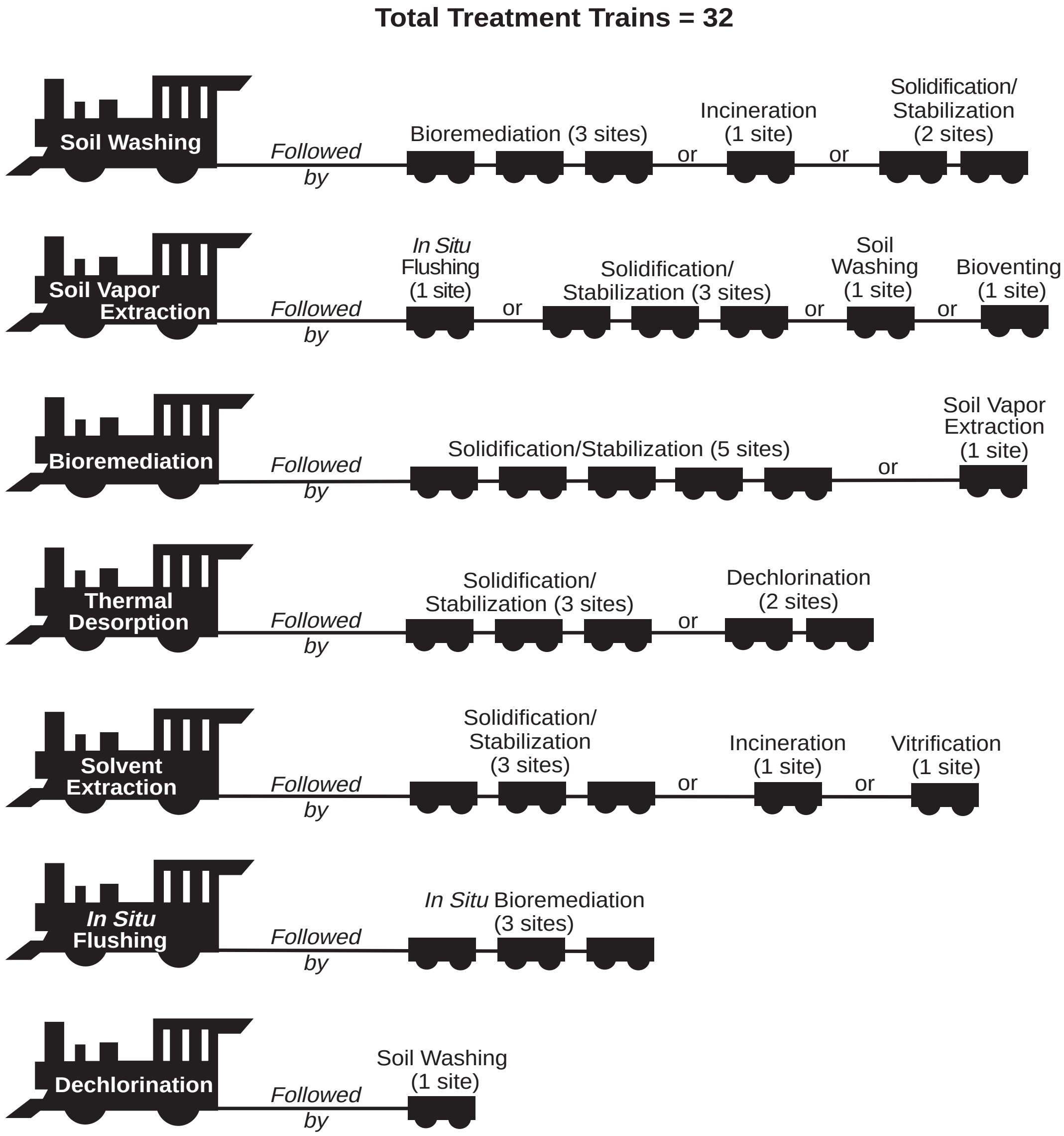
Previous EPA studies have shown that pump-and-treat technology alone is often insufficient to meet cleanup levels selected.[7] Until recently, contaminants in unsaturated soils were considered to be the most significant source of groundwater contamination. However, studies indicate that nonaqueous phase liquids (NAPLs) and contaminants captured or absorbed by soils in the aquifer are released slowly into the groundwater. Consequently, improved *in situ* groundwater remediation technologies are needed to treat this residual subsurface contamination.[8]

Three recent efforts have further expanded the information available on new technologies for groundwater and other media. The first is the establishment of the *Groundwater Remediation Technologies Analysis Center* (GWRTAC) at the National Environmental Technologies Applications Center (NETAC) in association with the University of Pittsburgh. This center develops and disseminates information on current *in situ* research, development, and demonstration efforts, and analyzes technology development trends. Section 3.5.4 describes how to contact the center. The second effort is the 1995 EPA publication of six technology status reports that describe existing research, demonstrations, and references for *in situ* abiotic groundwater technologies.[9] These efforts identified over 90 research and demonstration projects involving the six technologies: thermal enhancements (18 projects), surfactants (19 projects), treatment walls (23 projects), fracturing (12 projects), cosolvents (four projects), and electrokinetics (16 projects). Interest in these technologies, particularly treatment walls, is increasing rapidly. The third effort is the development of a database called the *Bioremediation in the Field System*, which was developed by the Bioremediation Field Initiative, an affiliation of government and industry representatives working jointly to document the use of bioremediation for soils and groundwater. This database includes data on more than 400 sites for which public information is available.[10]

2.5 Research and Development

Future technology use also will be influenced by technology development efforts, and the perceived needs of industry. EPA and other federal agencies currently are coordinating two technology development programs directed toward identifying and implementing research, development, and demonstration projects based on user needs. Under these programs, the Remediation Technologies Development Forum (RTDF) and the Clean Sites Public-Private Partnerships, 11 different technologies have been identified for further efforts (Exhibit 2-12).

Exhibit 2-10: Treatment Trains with Innovative Treatment Technologies Selected for Remedial Sites



Note: Includes technologies selected in FY 1982-1995 Records of Decision.

Source: U.S. EPA, Office of Solid Waste and Emergency Response, Technology Innovation Office, *Innovative Treatment Technologies: Annual Status Report (Eighth Edition),* EPA-542-R-96-010, November 1996.

All except one are technologies for *in situ* treatment of soil or groundwater, and five are bioremediation methods. The RTDF is a consortium of partners from industry, government, and academia who share the common goal to develop more effective, less costly hazardous waste characterization and treatment technologies.[11] RTDF achieves this goal by identifying high priority needs for technology development. For each priority need, the RTDF organizes an Action Team composed of organizations who share that interest, to plan and conduct collaborative laboratory and field research and development. Although federal agencies provide in-kind contributions and funding, the formation of teams is driven by the

Exhibit 2-11: Estimated Quantities of Soil to be Treated by Innovative Technologies at NPL Sites

Technology	Number of NPL Sites		Quantity (Cubic Yards)		
	Total Sites	Sites with Data	Range	Average	Total
Soil Vapor Extraction	137	118	11 - 6,200,000	250,130	29,515,300
In Situ Bioremediation	26	12	5,000 - 484,000	106,108	1,273,300
In Situ Flushing	16	12	5,200 - 750,000	97,383	1,168,600
Soil Washing	9	8	5,500 - 62,000	23,263	186,100
Ex Situ Bioremediation	43	35	400 - 208,000	34,591	1,210,700
Dechlorination	4	4	700 - 48,000	27,700	110,800
Solvent Extraction	5	5	7,000 - 100,000	27,540	137,700
Thermal Desorption	50	43	250 - 180,000	26,813	1, 153,000
Cyanide Oxidation	1	1			3,000
Contained Recovery of Oily Wastes (CROW™)	1	1			200
Physical Separation	1	1			8,000
Plasma High Temperature Metals Recovery	1	1			65,000
Vitrification	3	1			4,600
Total	297	242			34,836,300

Notes: Does not include sites conducting *ex situ* SVE or treating sediments or sludge. Includes technologies selected in Fiscal Year 1992-1995 Records of Decision.

Source: U.S. EPA, Office of Solid Waste and Emergency Response, Technology Innovation Office, *Innovative Treatment Technologies: Annual Status Report (Eighth Edition)*, EPA-542-R-96-010, November 1996.

organizations responsible for site cleanups. Five Action Teams have been established to date. More information on the RTDF is available from EPA's Technology Innovation Office (703-603-9910).

Through the Clean Sites Public-Private Partnerships for technology acceptance, EPA and Clean Sites, Inc., a nonprofit firm, develop partnerships between federal agencies, such as DOD and DOE, and private industry site owners (responsible parties, owner/operators) for the joint evaluation of full-scale remediation technologies.[11] The purpose of this program is to create demand for new technologies by allowing the end users of the technologies to be involved throughout the demonstration process. Typically, Clean Sites, with the assistance of federal agencies, identifies and characterizes a candidate federal facility, solicits industry participation, and brings together the facility and private companies. Based on common problems identified by these partners, the host facility arranges for the procurement of technologies for demonstration. The partners develop evaluation plans and conduct the demonstrations. Currently, there are six evaluation projects under this program. More information is available from the Technology Innovation Office (703-603-9910).

Based on the technologies listed in Exhibit 2-12, prospective users of innovative technologies are interested in *in situ* processes that are generally viewed as being cheaper, more acceptable to the public, and posing lower risk to workers. There is considerable interest in the use of SVE in conjunction with several other technologies, including dual-phase extraction, air sparging, dynamic underground stripping, and rotary steam drilling. Several processes entail the

Exhibit 2-12: Examples of Technology Needs Identified by Users Participating in Two Federal Programs

Medium	Public/Private Partnerships	Remediation Technologies Development Forum
In Situ Management of Soils	• Lasagna™ (electroosmosis, hydrofracturing treatment zones)	• Lasagna™ • Co-metabolic bioventing • Phytoremediation of metals
In Situ Management of Groundwater	• Anaerobic bioremediation • Permeable treatment walls • Air sparging	• Accelerated anaerobic bioremediation • Permeable treatment walls • Intrinsic bioremediation
In Situ Management of Soil and Groundwater	• Rotary steam drilling • Dual-phase extraction	• Not applicable
Ex Situ Management of Soil	• Enhanced bioslurry reactors	• Not applicable
Ex Situ Management of Groundwater	• Membrane separation	• Not applicable

creation of treatment zones (permeable barriers, microbial filters, and the Lasagna™ process) and the use of electric fields to mobilize both organics and inorganics.

EPA and other federal agencies have other active research and demonstration programs for most types of innovative cleanup technologies. Through the Superfund Innovative Technology Evaluation (SITE) program, EPA has, for a decade, been evaluating field-ready and emerging innovative technologies offered by specific companies. Under SITE, the Agency develops reliable engineering, performance, and cost data on these technologies by field testing them on hazardous wastes at existing sites or in a test that duplicates site conditions. EPA selects participants by soliciting and evaluating proposals, and enters into cooperative agreements with technology developers. By September 1996, EPA had completed 86 field demonstrations and 53 bench-scale or early pilot-scale projects.[12] Section 3.5.4 describes how to access SITE reports and other information. The program has less funding than in the past, and future funding may depend on a new Superfund law. More information on this program is available from the National Risk Management Research Laboratory (513-569-7696).

Lastly, to encourage the acceptance and use of innovative cleanup technologies, the Federal Remediation Technologies Roundtable sponsors a coordinated effort by federal agencies to document the cost and performance of remediation technologies. Case studies of selected ongoing and completed remediation projects are available on the Internet (http://www.frtr.gov).

2.6 Conclusions on Technology Trends

After a significant increase in the selection of treatment technologies, especially innovative technologies, in the early 1990s, the selection of several technologies has levelled off or decreased in the past two years, and the selection of containment has become more common. Most of the applications of innovative technologies for Superfund cleanups have been to treat organic contamination in soil. Three innovative technologies account for over 75 percent of innovative technology applications:

- SVE, which is primarily used to treat VOCs, is the most commonly used innovative technology. The selection of SVE relative to other technologies grew rapidly from 1986 to 1989, fluctuated for the next few years, and declined in 1995. Enhancements, such as methods to increase soil permeability or contaminant volatility, may expand its applicability and improve performance.

- Bioremediation is the second most frequently selected innovative technology, and its selection has remained fairly constant over the past several years. This trend may reflect a limit in the number of sites with contaminants that can be treated by bioremediation in its current state of development. The contaminants most often treated by bioremediation are petroleum hydrocarbons and PAHs. Current bioremediation research could lead to improved performance and expand the types of contaminants amenable to biological degradation.

- Thermal desorption is the third most frequently selected innovative technology. The frequency of selection for this technology has remained relatively constant over the past five years. It is used primarily to treat VOCs, (particularly when SVE is not feasible), and SVOCs, primarily PAHs and PCBs. Soils containing both metals and organics present another major treatment opportunity, since organics will volatize at relatively low temperatures. Residuals containing metals then can be treated by another technology, such as solidification / stabilization.

Relatively few innovative treatment methods are being selected for metals-contaminated soils. The most widely used technology for the treatment of metals is solidification / stabilization, which has been selected for 30 percent of the source control projects at Superfund sites. The selection of this technology has declined during the past two years. Although solidification / stabilization has several advantages, including low cost, questions remain concerning its effectiveness over time. Consequently, the sites may require long-term monitoring. New separation technologies such as electrokinetics could provide alternative methods for remediating metals in the future. Additional field tests of these and other technologies are needed.

Despite recent advances, about 93 percent of remedies selected for groundwater continue to rely on conventional pump-and-treat technologies. Bioremediation and air sparging are the most widely used innovative *in situ* approaches. Usually, these technologies are applied in conjunction with pump-and-treat. Research and demonstration efforts to develop innovative methods for the treatment of groundwater, which are enumerated in Chapter 3, include both biological and abiotic *in situ* processes. Chapter 3 addresses additional factors that may affect the demand for innovative technologies for Superfund cleanups.

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